MEASUREMENT OF TEMPERATURE DISTRIBUTION USING THE CURRENT INJECTION MRI

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***Abstract*-A new temperature distribution measurement method using the current injection MRI is proposed. Since electrical impedance of biological tissues is very sensitive to their temperature, formation of current density inside the tissues is strongly dependent on the temperature distribution inside the tissues when external current is applied to the tissues during the current injection MRI. Therefore, the phase change at the image domain has correlations with the temperature change inside the tissues. Both simulation and experimental results have shown that a small change of temperature distribution can be measured using the current injection MRI.**

***Keywords*-Current injection, electrical impedance, magnetic resonance imaging, temperature measurement**

I. INTRODUCTION

Recently, many research groups have been developing temperature imaging techniques for interventional studies using an MRI(Magnetic Resonance Imaging) system[1,2]. Among the MRI interventional technologies, the imaging guided thermal therapy is believed to be of foremost importance in the clinical area. In the imaging guided thermal therapy, accurate monitoring of the temperature distribution inside the human body is very crucial. Among the many MR temperature imaging techniques reported so far, the chemical shift temperature imaging technique is known as the most efficient one[2]. However, the technique has not been widely used clinically because of its very low sensitivity to the temperature. In this paper, we have analyzed the effect of local temperature rise on the phase image obtained with external current injection. Since the temperature coefficient of tissues' electrical impedance is as big as several %/^{o}C[3], it is expected that the local temperature rise can make a big change in the phase image. Simulation results obtained by the finite element method and experimental results obtained by a 0.3 Tesla MRI system are presented.

II. METHODOLOGY

To analyze the effect of local temperature rise on the phase image obtained with the current injection MRI, we have made a simulation phantom as shown in Fig. 1. The phantom has two regions. Region 1 represents the background region and region 2 represents the region of temperature rise. It is assumed that the electrical conductivities at both regions are the same initially, but the electrical conductivity σ_2 has increased at the time of current injection. On top and bottom of the phantom are electrodes to inject electrical current into the phantom. A current source injects bipolar current pulses into the phantom. A typical spin echo pulse sequence combined with the bipolar current pulse is shown in Fig. 2. When the current pulse is applied to the phantom, the current diffuses inside the phantom producing a current density $J(x,y)$. The current density, then, generates an extra magnetic field $B_{ext}(x,y)$. Since formation of the current density $J(x,y)$ is governed by the conductivity distribution $\sigma(x,y)$, the extra magnetic field is also related with the conductivity distribution.

The phase image $\theta(x,y)$ obtained by the current injection MRI will be given by,

$$\theta(x,y) = 2\gamma B_{ext}(x,y)T \qquad (1)$$

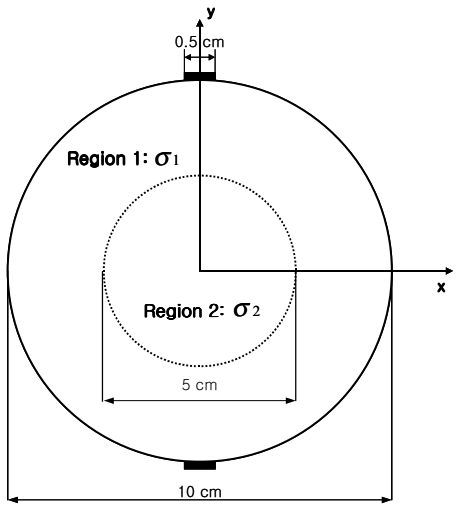

Fig. 1. The FEM simulation phantom. Region 2 represents the region of local temperature increase.

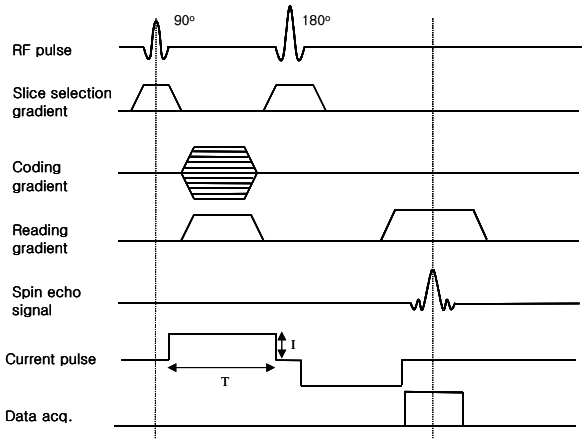

Fig. 2. The current injection MRI pulse sequence

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Abstract

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where T is the current pulse width and γ is the gyromagnetic ratio. To analyze the effects of conductivity variation caused by a thermal therapy procedure, we have calculated phase variation $\theta(x,y)$ inside the phantom using the finite element method. The conductivity variation was given by the order of 5% considering that the temperature coefficient of the ionic solution is about 2%/^{o}C.

III. RESULTS

We have analyzed the effect of local conductivity variation on the phase image using the finite element method. In the analysis, the current amplitude was set to 100mA which is considered not to give hazardous effects on the living tissue. The bipolar current pulse width was set to 50 msec so that the bipolar current pulse can be easily adopted in the typical spin echo pulse sequence. In Fig.3, the current density changes along the horizontal axis at the center of the phantom are shown as the electrical conductivity inside the region 2 increases.

In Fig. 3, we can observe increase of current density inside the region 2 as the electrical conductivity at the region 2 increases. The current density change causes the magnetic field distribution change inside the phantom. We have calculated the magnetic field change as follows,

$$\Delta B(x,y) = B_{ext}(x,y,\sigma_2=A) - B_{ext}(x,y,\sigma_2=B) \qquad (2)$$

In Fig. 4, we show $\Delta B(x,y)$ when A=0.77 siemens/m and B=0.70 siemens/m. In the region 2 where electrical conductivity has changed due to the temperature rise, $\Delta B(x,y)$ increases in a linear fashion along the horizontal direction. The maximum $\Delta B(x,y)$ appears at the boundary of the region 1 and 2. With the current of 100 mA, the maximum ΔB is about 1.5×10^{-8} Tesla. This magnetic field change can make a phase change of 23 degrees when the current pulse width is 50 msec. The phase change, 23 degrees, is made by 10 % rise of the conductivity in the region 2. Considering that the average temperature coefficient of biological tissues' electrical conductivities is about 2%/^{o}C, it can be said that the phase change is caused by 5 degree temperature rise.

To verify the simulation works, we have performed experiments using a 0.3 Tesla animal MRI system. The experiment set-up is shown in Fig. 5.

A cylindrical phantom with the diameter of 70mm and the height of 80mm is made of the mixture of NaCl and $CuSO_4$ solution. The electrical conductivity of the phantom is about 1.3 siemens/m when the temperature is 25^{o}C. With a constant current source, we applied bipolar current pulses to the phantom. The amplitude of the current pulse was 33 mA and the pulse width was 48 msec. In Fig. 6, we show some cut views of the phase images for some phantom temperatures. The image was obtained with TR=300msec and TE=100msec. The imaging matrix size was 128*128. In Fig. 6, we can observe increase of phase change as the phatom temperaure rises.

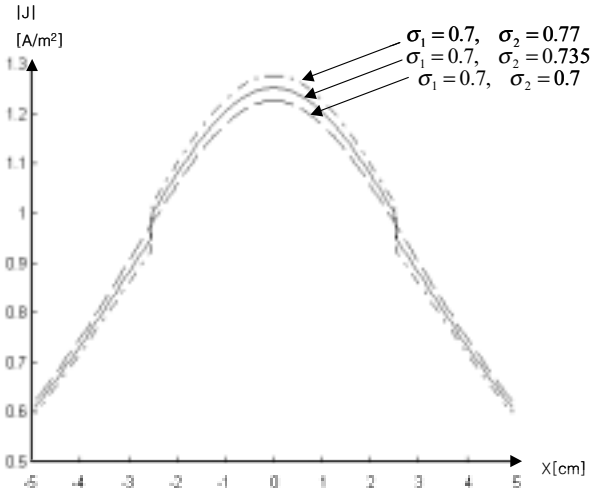

Fig. 3. Current densities along the horizontal axis at the center of the phantom.

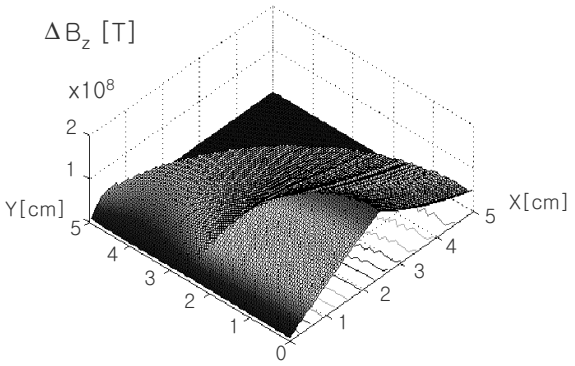

Fig. 4. Magnetic field change when the electrical conductivity at the region 2 is changed from 0.7 siemens/m to 0.77 siemens/m.

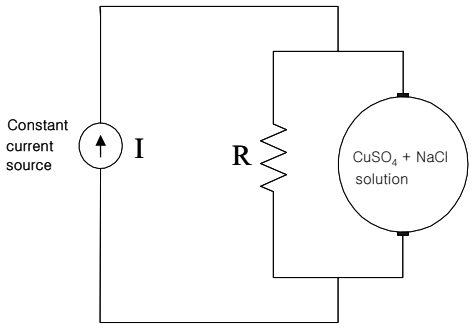

Fig. 5. Experiment set-up to measure phase changes caused by temperature rise inside the phantom.

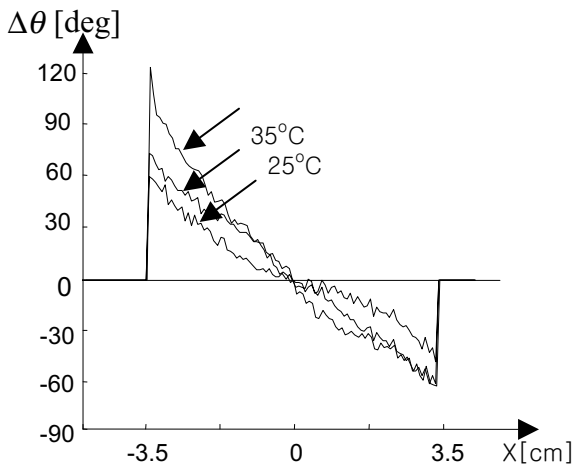

Fig. 6. Cut views of the phase images when the phantom temperature is 25°C, 35 °C, and 45 °C.

IV. Discussions and conclusions

We have found that the local conductivity change, caused by the temperature rise during a thermal therapy, makes quite measurable phase changes in the current injection MRI.

Although it is necessary to inject electrical current into the tissue of interest during the scan, we think that the current injection MRI technique could be used to monitor the tissue temperature during the thermal therapy. To reconstruct temperature maps using the phase change information, we need to adopt iterative reconstruction procedures similar to the one used in electrical impedance tomography. In addition, temperature calibration phantoms without any current insulating barriers inside them have to be developed for efficient and accurate temperature calibrations. Even though we have not yet developed a technique for reconstructing the temperature map from the phase image, we believe that the phase change information can be used to monitor the tissue temperature.

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